Iterative Tensor-Based Registration

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Introduction: Image registration has many important applications. The ability to correct the data quickly and accurately is paramount. We revisit the use of moment of inertia [1, 2] as a means to register rigid body motion. We have added to it, however, a smoothing filter that appears to eliminate the deleterious role of Gibbs ringing and interpolation difficulties to obtain very accurate corrections in translations and rotations. To this we then add an iterative procedure in which the filter is reapplied after correction of the original rotated data. This new iterative approach is fast and offers a well controlled approach to registration correction.

Materials and Methods: High resolution 3D gradient echo images were acquired with an in-plane resolution of 1 x 1 mm and a slice thickness of 1 mm for a matrix size of 256 x 256 x 256 pixels. These images served as our simulated images. The image was then low pass filtered with a Hanning filter and then the usual moment of inertia matrix was used to extract the shift in the center-of-mass and the rotation angles. The Fourier Transform shift theorem was used to return the image to its original position before applying the rotation matrix to the image. After correction, the new image was again filtered and the residual shift and rotation calculated again. If the correction had been perfect this would be zero. However, this is usually not the case. Once again, a shift and rotation are performed and the process repeated iteratively until a specific threshold was attained. Finally, data were re-sampled with an improved linear interpolation paradigm, which based on the rotation parameters, applies to the intra-pixel re-sampling location, a shift towards the center of gravity of the pixel. This paradigm corresponds to the interpolation surface being increasingly accurate in the approximation of the intensity value to be determined and it is similar to what reported earlier [3].

Results: Figure 1 shows the advantage of using the Hanning filter. The original MR image is shown in (a), the resulting image after registration and interpolation, without and with the application of the filter respectively are shown in (b) and (c), and the corresponding difference images in (d) and (e). Artifacts were reduced as shown in (e) with respect to (d). Figure 2 shows the advantage of using the improved linear interpolation paradigm. Particularly, figure 2a, 2b and 2c show respectively the original MRI, the MRI re-sampled with classic linear interpolation and the MRI re-sampled with the improved linear paradigm. Figures 2d and 2e show the corresponding difference images and the visible improvement in (e) with respect to (d). Figure 3 shows the advantage of the iterative process used for the calculation of the registration parameters, two iterations were sufficient to achieve convergence, also, subtraction images shown respectively in figures 3d, 3e, display image quality improved in (e) with the progression of the iterations. In figures 1 and 3, the misplacement that was motion corrected was 0.025 of the voxel size applied concurrently along the X and Y axes. In figure 2, a rotation of 5 degrees about the X axis was motion corrected. Figure 4 shows the plot of the accuracy for shifts that varied from 0.025 to 0.5 of the voxel size, at the end of the first iteration in (a) and at the end of the iterative process in (b), and the plot of the accuracy for rotations around the Z axis (c) from 3 to 15 deg. Three iterations at the most were sufficient to reach an average value of accuracy that was $4 \cdot 10^{-4}$ mm along X and Y, 10^{-3} mm along Z (not shown) or 0.006 deg.

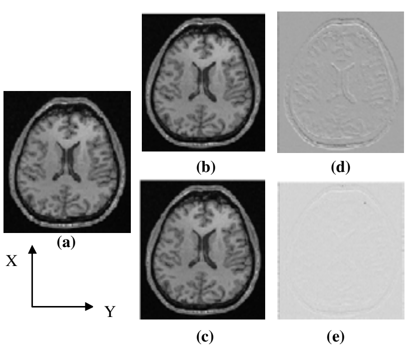

Fig. 1 Hanning filter

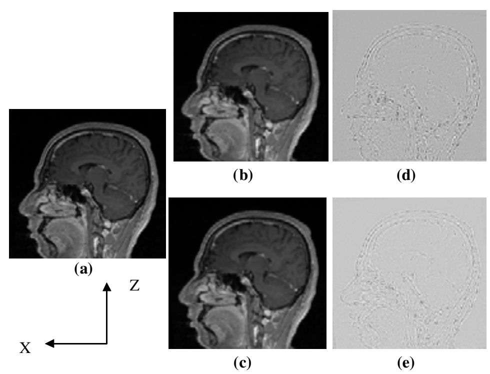

Fig. 2. Interpolation

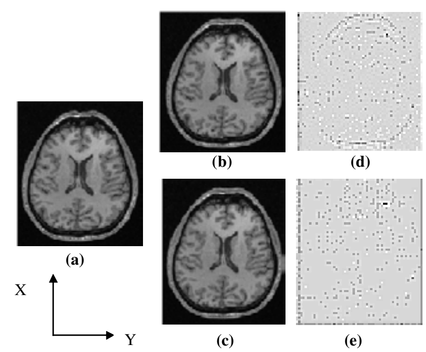

Fig. 3. Iterations

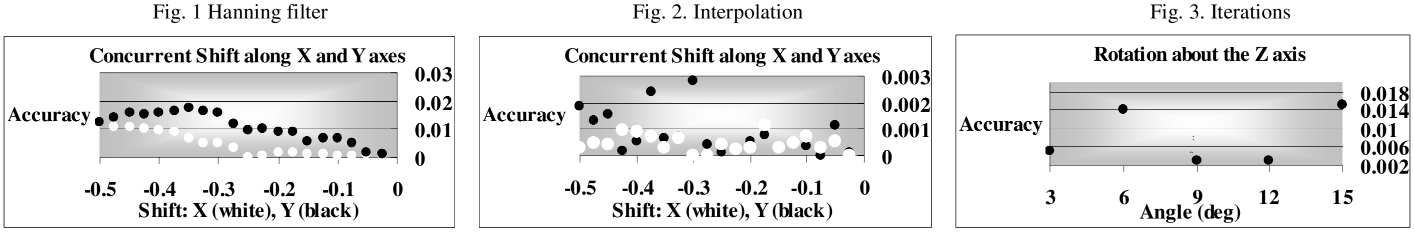

Fig. 4. Accuracy after one iteration (a), and after multiple iterations (b); units are in fractions of the voxel size, and for rotations about the Z axis (c), units are in deg.

Discussion: Recent investigations [2] have proposed an extension to the tensor-based registration method by combining two alignment methodologies which reports to have sub-voxel accuracy: (i) the principal axes registration method introduced in [1], and (ii) the point-based registration method which was extensively studied in [4]. Also, the quality of the resulting registered brain images has been studied by others [5-7], and it has been reported that interpolation affects the quality of the images after registration. We have found that both accuracy and image quality after registration are greatly improved thanks to the following: (i) applying the Hanning filter, (ii) iterating the tensor-based registration, and (iii) using the improved linear interpolation paradigm. The Hanning filter was most effective in reducing Gibbs ringing effects on center-of-mass calculations. The error in translation was reduced to less than 0.1% of a voxel and less than 0.01 degrees. In conclusion our algorithm should prove useful for very accurate MRI co-registration for a variety of important practical applications.

References: [1] N.M. Alpert et al., J Nuclear Medicine 31: 1717-1722, 1990; [2] C. Ciulla et al., Brain Topography 14(4): 313-332, 2002; [3] T. Blu et al., IEEE Trans. Imag. Proc. 13(5): 710-719, 2004; [4] C.R. Maurer et al., IEEE Trans. Biomedical Imag. 16(4): 447-462, 1997; [5] S. Grootoonk et al., Neuroimage 11: 49-57, 2000; [6] L. Freire et al., Neuroimage 14: 709-722, 2001; [7] J. Tsao, IEEE Trans. Med. Imag. 22(7): 854-864, 2003.